Geobotanical remote sensing Techniques
For
Natural Gas Transmission Infrastructure Systems
using advanced
Hyperspectral, multispectral, and Radar Imaging

by

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LLNL and PG&E Geobotanical Remote Sensing Program for Pipeline Monitoring

- We are applying our geobotanical remote sensing techniques for
  - detection and discrimination of gas pipeline leaks
  - detecting and evaluating third party damage
  - monitoring transmission system reliability and risk modeling
  - vulnerability assessment and monitoring for Homeland Security
- We use state of the art high spatial resolution imagery
  - AVIRIS Airborne Hyperspectral visible and near IR by NASA JPL
  - MASTER multispectral IR imagery provided by NASA AMES
  - Satellite high resolution multispectral imagery By IKONOS and Digitalglobe
- PG&E is collaborating in all phases of the program and Is providing
    - immediate notification of new discovered leak
    - exact leak locations and technical details of the leak type
    - ICONOS and Early Bird 2 satellite imagery
    - site access for ground truth and historical site info

Hyperspectral Geobotanical Remote Sensing
UC Santa Cruz, LLNL, PG&E Collaboration

- **Principal Investigators**
  - **Dr. William L. Pickles, LLNL, Energy and Environment**
  - **Donald Price, PG&E, San Ramon**
  - **Prof. Donald C. Potts, UC Santa Cruz, Biology**
  - **Prof. Eli A. Silver, UC Santa Cruz, Earth Science**
- **Current PH. D. Graduate Students at UC Santa Cruz**
  - **Wendy Cover, UCSC New student, Pipeline and CO2 storage**
  - **Ty Kennedy Bowdoin, UCSC Research Associate Pipeline and CO2 storage**
  - **Brigette Martini, UCSC Earth Science, Lead on Geothermal**
  - **Daria Siciliano, UCSC Ocean Science, Lead on Coral Reefs, Elkhorn**
  - **Stacy Jupiter, UCSC Biology, Lead on Pit River, and Elkhorn**
  - **Mimi D'Iorio, UCSC Ecology, and USGS Pacific Science Center, Lead on coastal Mangroves in Hawaii**
- **USGS Pacific Science Center**
  - **Susan A. Cochran, USGS, Coral Reefs, Elkhorn Slough**

Geobotanical remote sensing

- "Geobotanical remote sensing" uses both the plants and the geology to understand a region fully
- We are a multi-disciplinary collaboration involving
  - biologists
  - ecologists
  - geologists
  - sensor physicists
  - industry natural gas transmission professionals
- LLNL, UCSanta Cruz, USGS, Chevron, and PG&E

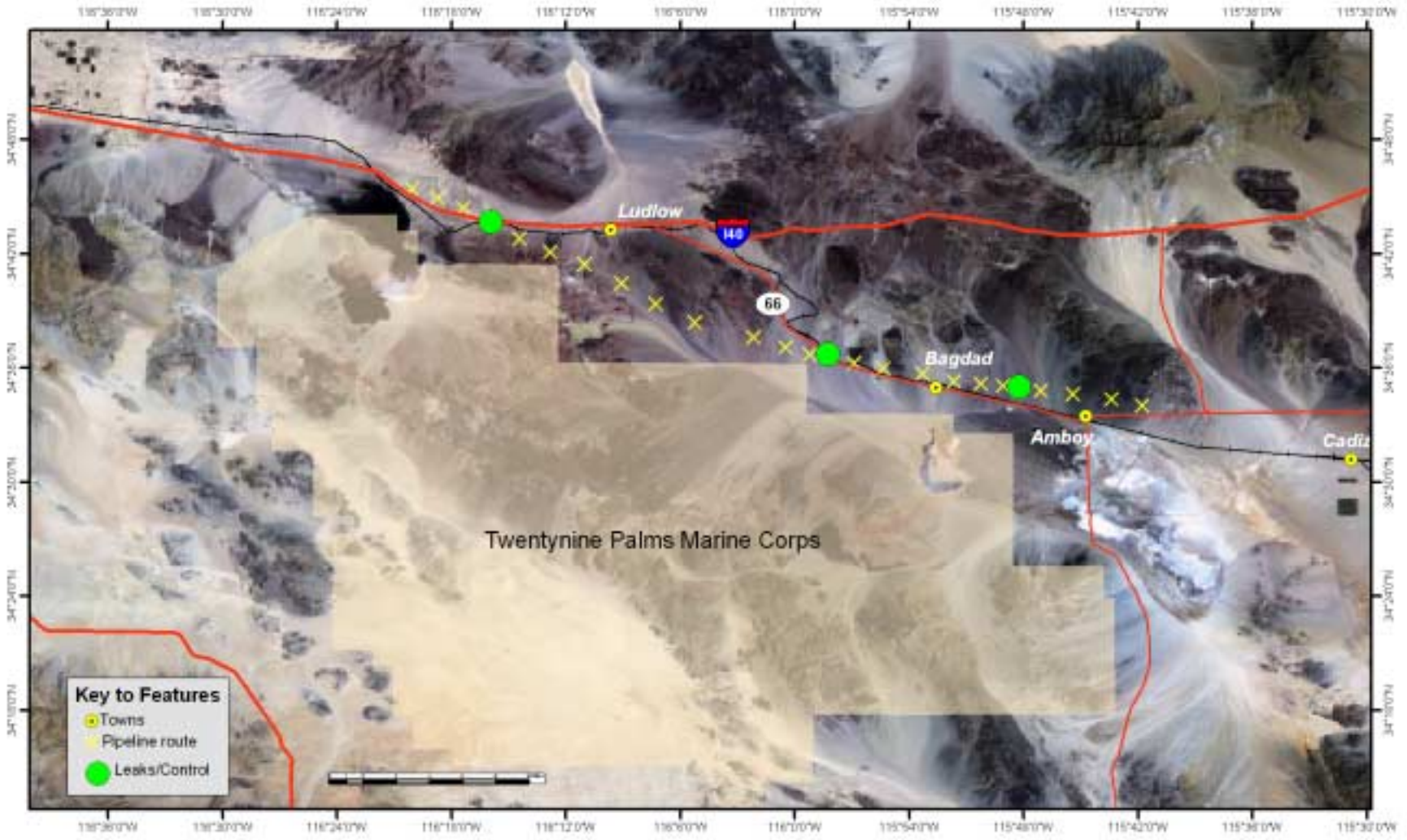
UCSC/ LLNL 3 m spatial resolution hyperspectral and multispectral imagery

- The high spatial resolution hyperspectral, multispectral and radar, imaging systems we use have the ability to map
  - soil types and disturbed soil
  - potential new and historical landslides
  - plant species types
  - plant health within species types
  - manmade disturbances and objects
  - water and water contents
- Large regions can be imaged quickly at reasonable costs

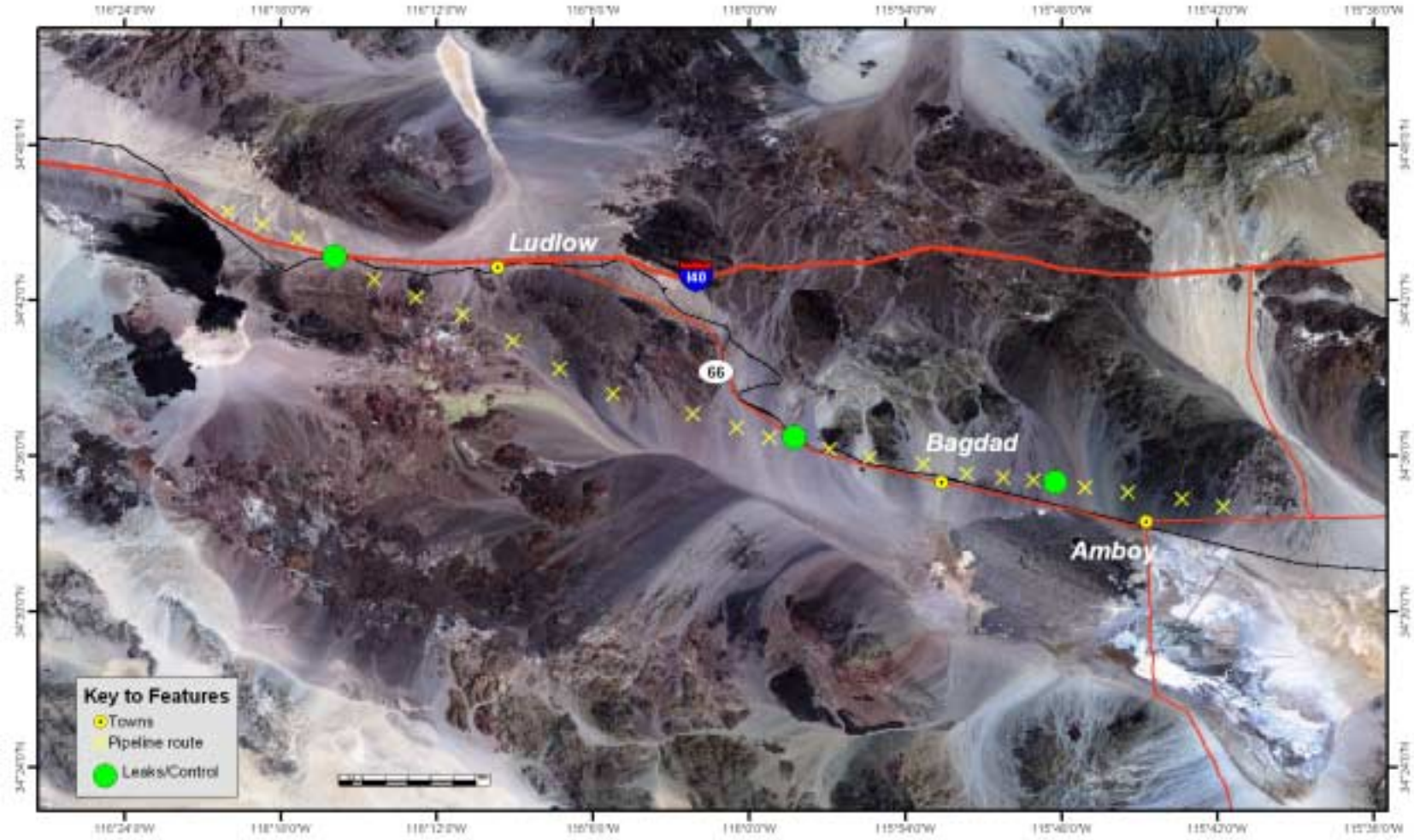
PG&E provides pipeline leak information

- 3-15-02 PG&E provided news of newly discovered leak locations
- 3-20-02 LLNL requested an AVIRIS hyperspectral low altitude acquisition of the leak area
- 3-22-02 LLNL requested a MASTER 50 Band visible and thermal IR acquisition of the leak area
- 3-28-02 NASA Approved both AVIRIS and MASTER to acquire the site of the leaks
- 4-7-02 MASTER acquisition successfully took place
- 4-12-02 AVIRIS acquisition successfully took place
- Master imagery was delivered to us in June
- We still do not have the AVIRIS imagery

PG&E # 300 pipelines with two leak points



Flightlines Amboy to Ludlow X X X



Ludlow Leak

- Close up of Ludlow leak
- MASTER RGB
- pipeline disturbed earth signatures
- leak repair disturbed earth
- Railroad
- HWY40
- Birms
- drainage channel under RR and HWY
- Actual imagery is viewable using ENVI on my laptop

Ludlow Leak

- Don Price with GPS
- pipeline markers
- area where leak has been repaired
- HWY 40

Ludlow leak area

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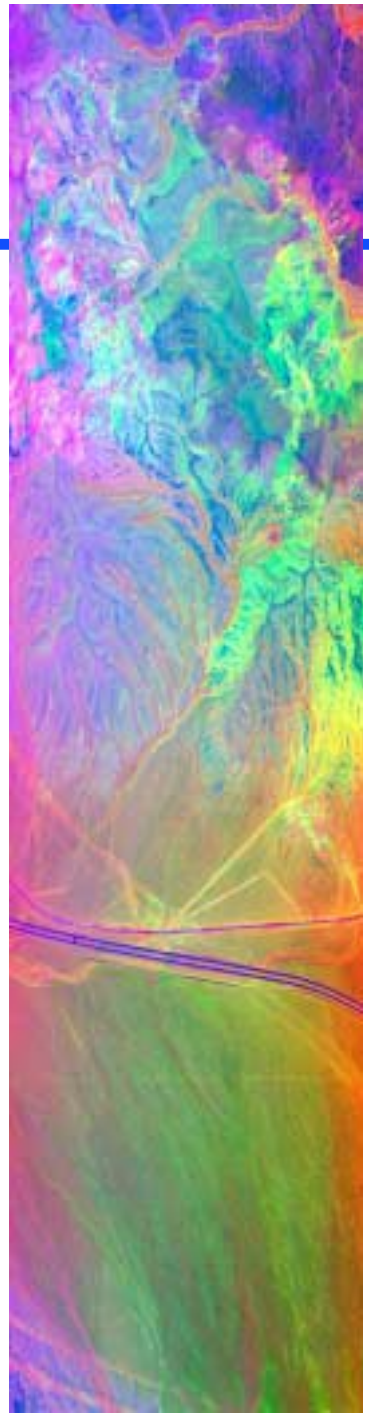
Repaired Leak area covered with gravel

MNF Ludow Leak

- Minimum noise Fraction transformation in pseudo color
- leak west of Ludlow
- leak point between is HWY 40 and railroad tracks
- flash flood birms apparent



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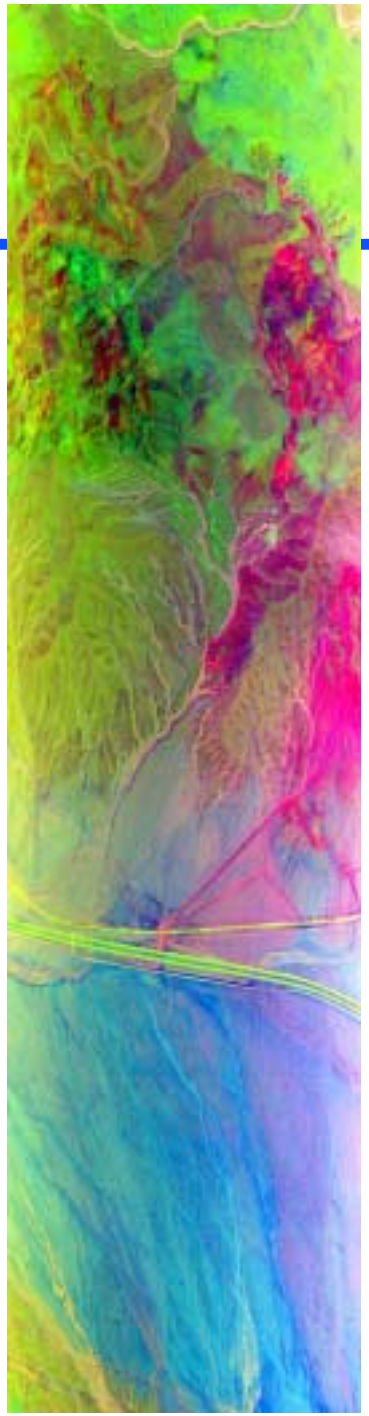
Ludlow leak MNF

- Using different MNF transformed bands emphases features differently
- MNF Pseudo color



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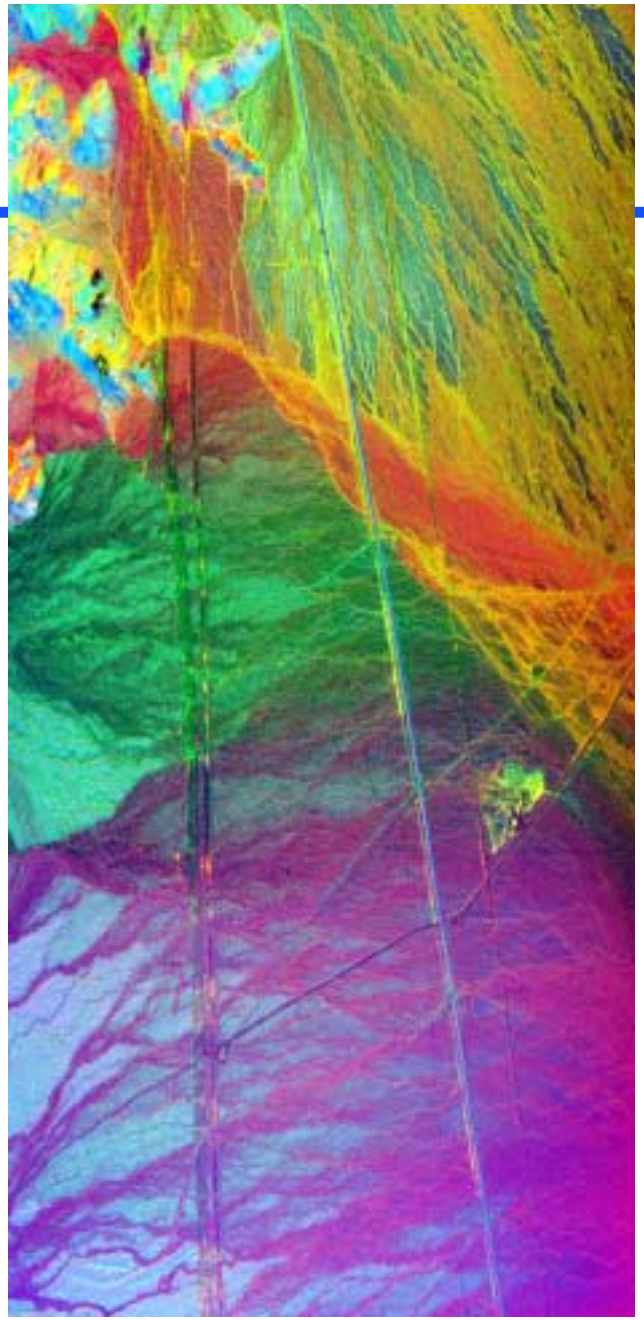
Master Amboy PPI

- Purest Pixel Transformation of Master bands (PPI)
- Pipelines east of Amboy
- Pipelines are buried
- image shows very distinctive permanent signatures of disturbed earth where pipelines are buried

Amboy MASTER MNF

- MNF transform Pseudo color
- pipelines are buried
- Note distinct signatures along pipeline
- Drainage patterns are revealed
- access roads
- trails
- Village of Amboy
- HWY 66
- Railroads



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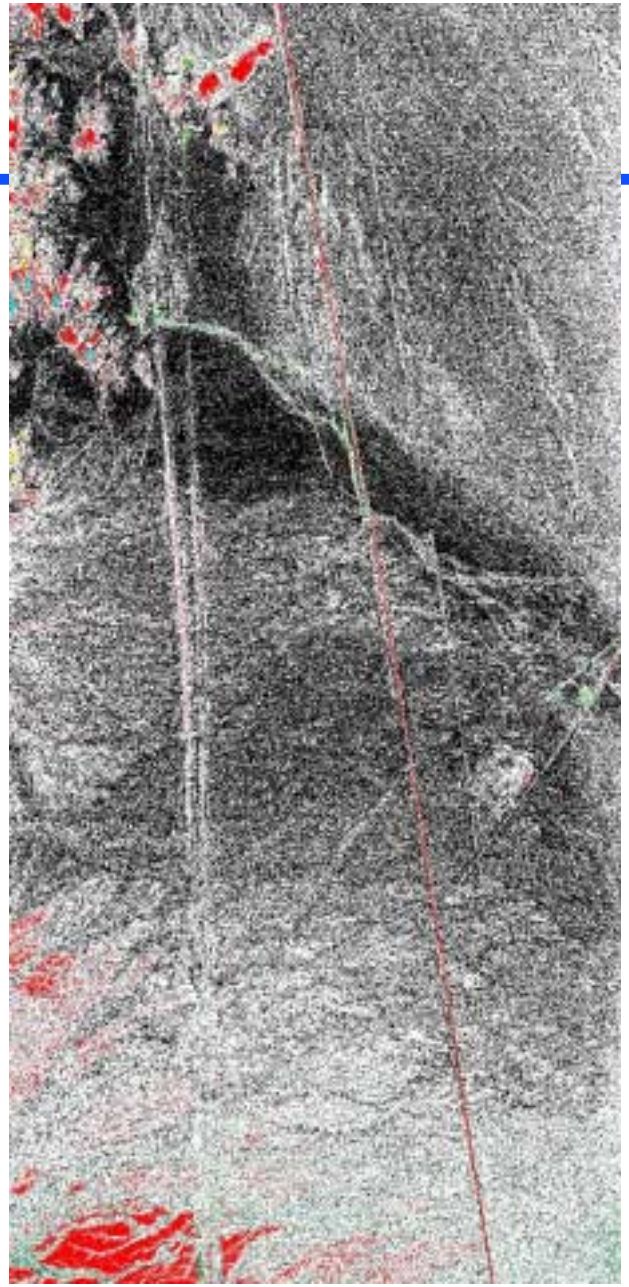
Amboy

- Regions of interest derived for MNF transformation MNF transform shown on top of the PPI transformation
- RR track bed and other areas show similar gravel type RED
- borrow pits for railroad bed gravel
- pipelines disturbed earth signatures are different



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RR roadbed gravel is different

Repaired Amboy Leak area

Amboy Leak repair underway

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Actual Leak

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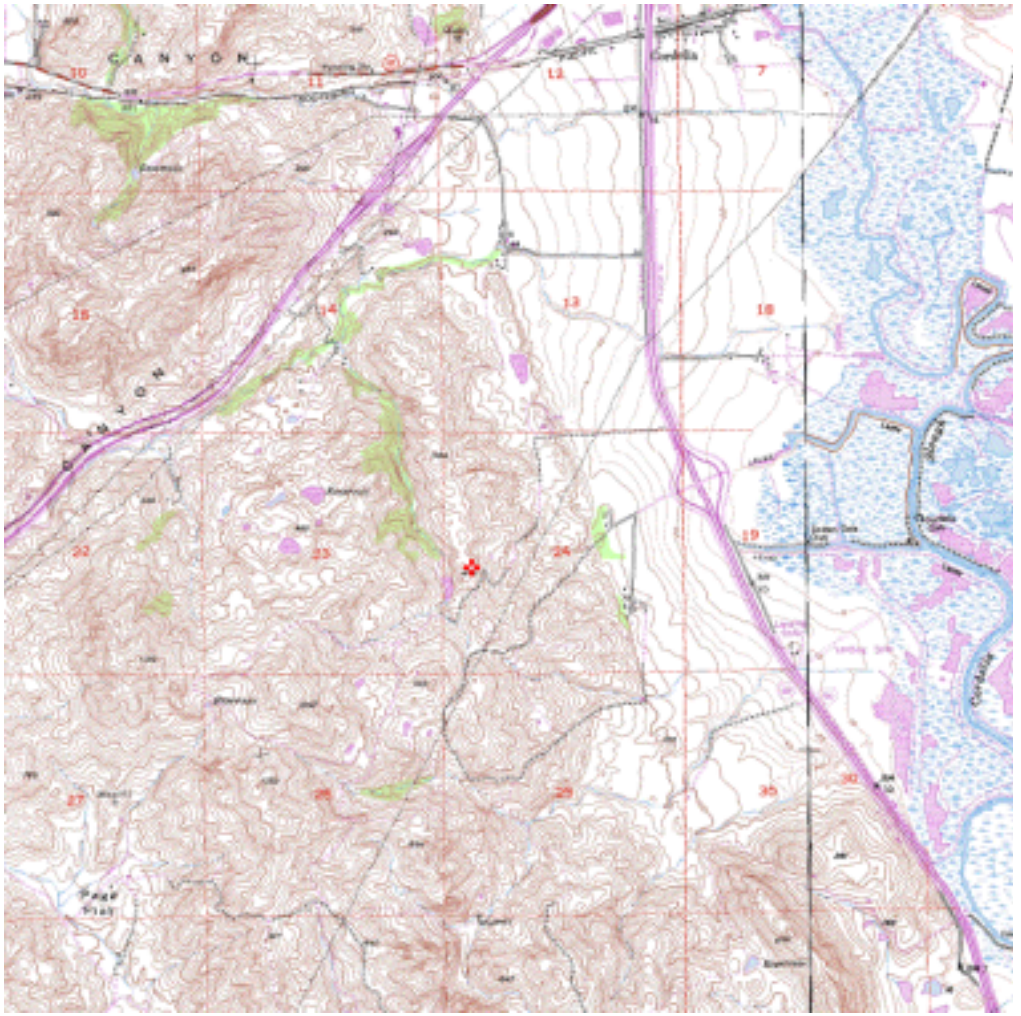
Important features of our Geobotanical remote sensing methods

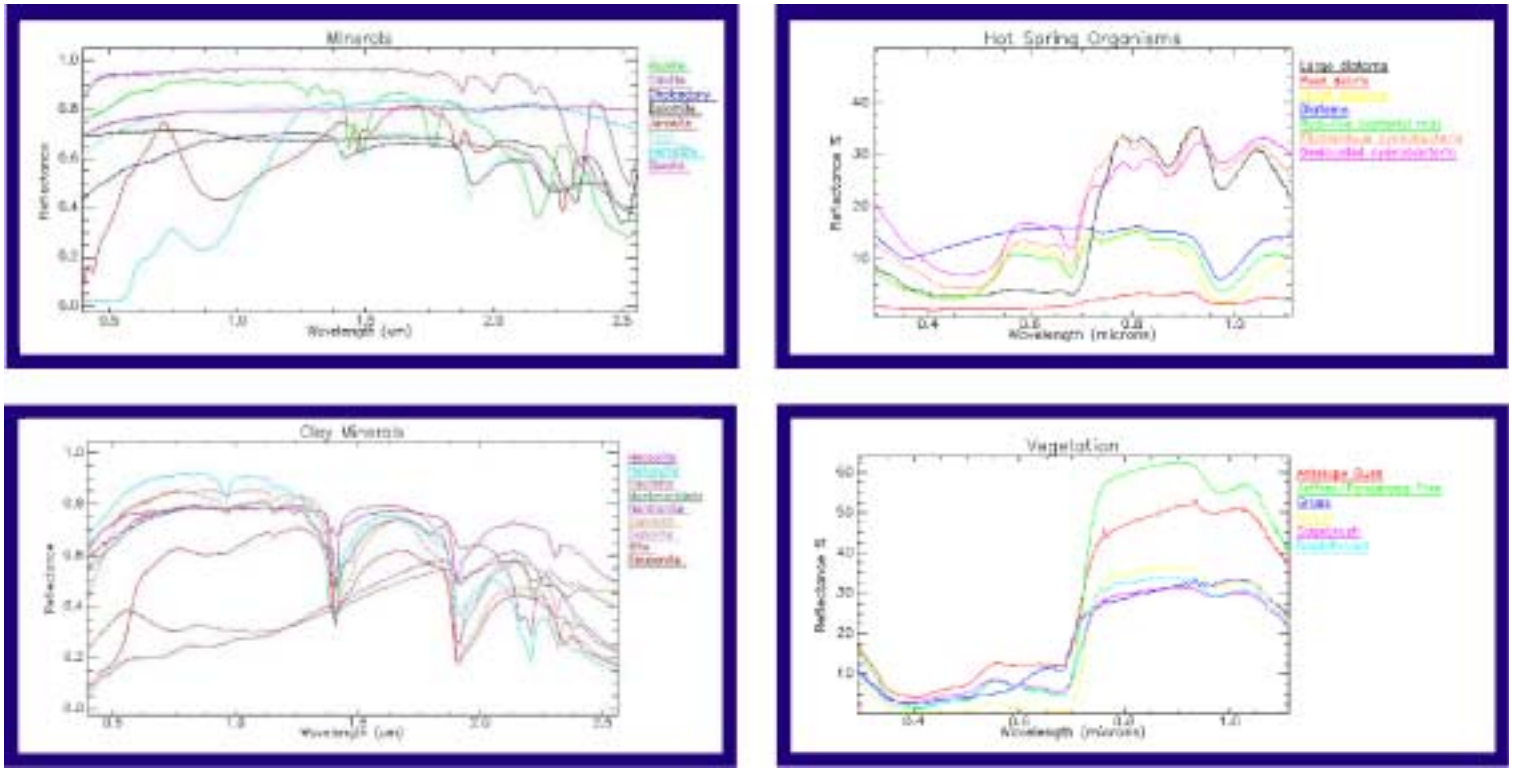
- Use Airborne imagery for “State-of-the-art” spatial resolution to reveal critical details (3 to 5 meters) and 0.6 meter satellite pan
- Excellent wavelength resolution for identification of objects
- High signal to noise ratio
- Wide area synoptic imaging to expose patterns
- Commercial image analysis programs to insure a smooth transfer to operational status
- Define the real roles of “ground truth” measurements
- Define the minimum set of on the ground measurements needed

Cordellia CA pipeline landslide Site

- Don Price from PG&E has a complete presentation on the work done at the Cordellia site



Hyperspectral imaging spectroscopy



The distinctive spectra allows identification of minerals, plant species, plant health, hot spring organisms, and soil types in the image

B Martini UCSC

Hyperspectral Imaging Program Web Sites

- An overview of the newly emerging field of hyperspectral geobotanical remote sensing and the collaborative team at LLNL and University of California Santa Cruz developing these techniques can be viewed at http://emerald.ucsc.edu/~hyperwww/ and http://emerald.ucsc.edu/~hyperwww/proj.html

- The promising new results that include the discovery of hidden faults at Mammoth Mountain can be viewed at http://emerald.ucsc.edu/~hyperwww/mammoth.html

Hyperspectral Imaging future

- We expect that commercial hyperspectral satellites will be operational in the next year or so. Please refer to the imaging sensor table at http://emerald.ucsc.edu/~hyperwww/instruments.html which is on the UCSC geobotanical remote sensing web site.
- We also expect to see more and improved airborne hyperspectral imaging services available for hire. This should allow for continued hyperspectral imaging over many areas in the western US.

Talks/Proceedings/Posters

- Martini, B.A., Cochran, S.A., Silver, E.A., Pickles, W.L., Potts, D.C. (1998). Geological and geobotanical characterization of a hydrothermal system using hyperspectral imagery analysis, Long Valley Caldera, CA. EOS. Fall 1998 AGU meeting.

- Martini, B.A., Cochran, S.A., Silver, E.A., Pickles, W.L., Potts, D.C. (1999). Geological and geobotanical characterization of a geothermal system sing hyperspectral imagery analysis, Long Valley Caldera, CA. Proceedings of the Thirteenth International Conference on Applied Remote Sensing. Vol. 1., p.337-341

- Martini, B.A., Silver, E.A., Pickles, W.L., Potts, D.C. (1999). Geological and geobotanical studies of Long Valley Caldera and Mammoth Mountain, CA utilizing new high resolution hyperspectral imagery. EOS. Fall 1999 AGU meeting

- Martini, B.A., Silver, E.A., Potts, D.C., Pickles, W.L. (2000). Geological and Geobotanical Studies of Long Valley Caldera, CA, USA Utilizing New 5m Hyperspectral Imagery. Proceedings of the IEEE International Geoscience and Remote Sensing Symposium. July 2000

- Martini, B.A., Silver, E.A., Potts, D.C., Pickles, and W.L. (2000). Insights into the Hydrothermal, Magmatic, and Structural Systems of a Restless Caldera, Long Valley Caldera, CA, USA, Proceedings of the Fourteenth International Conference on Applied Geologic Remote Sensing. p. 28-35

- B. A. Martini, E. A. Silver, W. L. Pickles, (2000) “Hyperspectral Remote Sensing for Research and Monitoring in Active Volcanic Regions”, American Geophysical Union (AGU), San Francisco, paper V22F-05, December, 2000

- Brigette A. Martini, Eli A. Silver, Donald C. Potts, (2001), Hyperspectral Remote Sensing in Long Valley Caldera: Issues of Scale, Resolution, and Signal to Noise, Summaries of the Tenth JPL Airborne EarthScience Workshop, NASA JPL, Pasadena CA, February 27-March 2, 2001

- Brigette A. Martini, Eli A. Silver, New Prospectives on Old Problems, Hyperspectral Imaging an Active Volcanic Environment, Long Valley Caldera CA, USA, Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2001, Sydney Australia, August 2001

Hyperspectral Imagery Approach

- Use HyVista corp.'s HyMap, and NASA JPL's AVIRIS airborne, visible and near IR reflected light imaging spectrometer systems.
- HyMap has a spatial resolution of 1 to 5 meters in 128 wavelength bands. http://www.hyvista.com/ AVIRIS can do 4 m and 224 bands
- Detect and discriminate individual species of plants, water, soils and geological formations using the spectral signatures in the images.
- Analyze for plant species distributions and their relative health along with a detailed understanding of the local geology.
- Distinguish terrestrial and aquatic plant species, many types of geological formations and soil types, and many different types of human activities.
- Determine signatures for geothermal water and soil temperature at plant root depth, CO2 releases, altered minerals, plant species mix modifications around geothermal springs and distinctive algae growth in geothermal springs in large complicated areas.

AVIRIS vs. HYMAP comparison

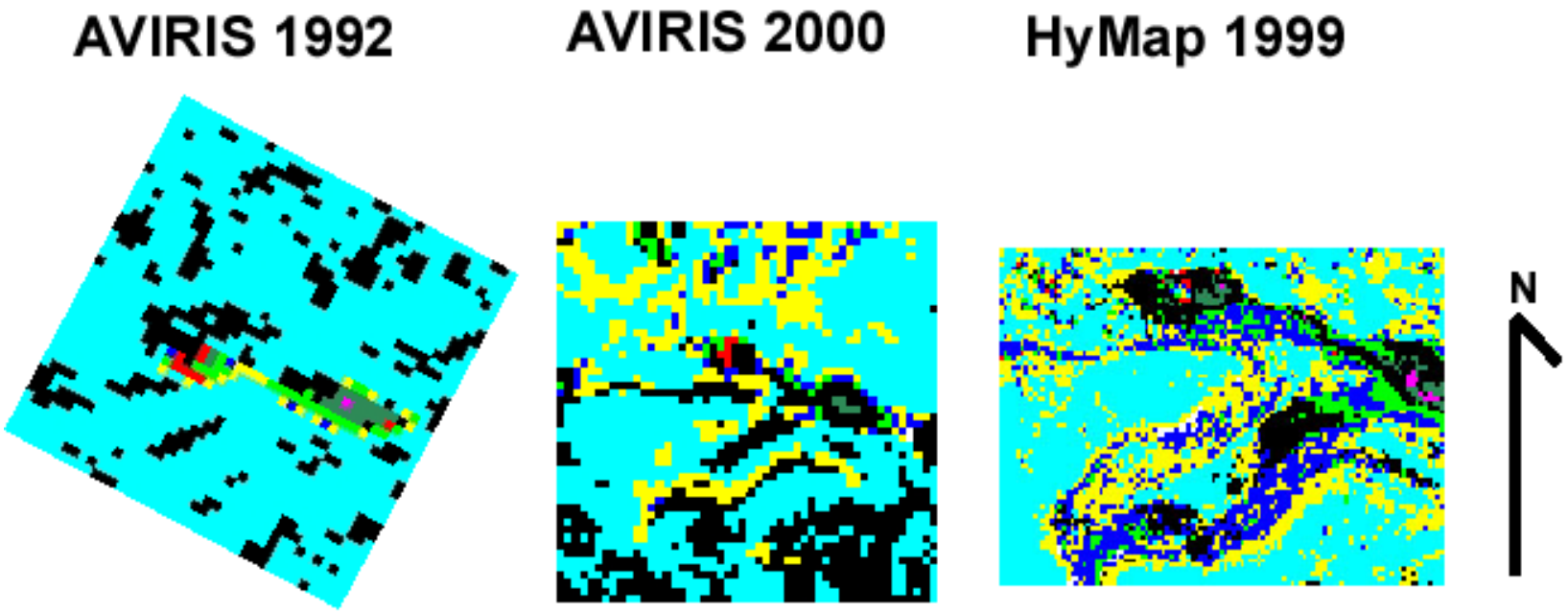


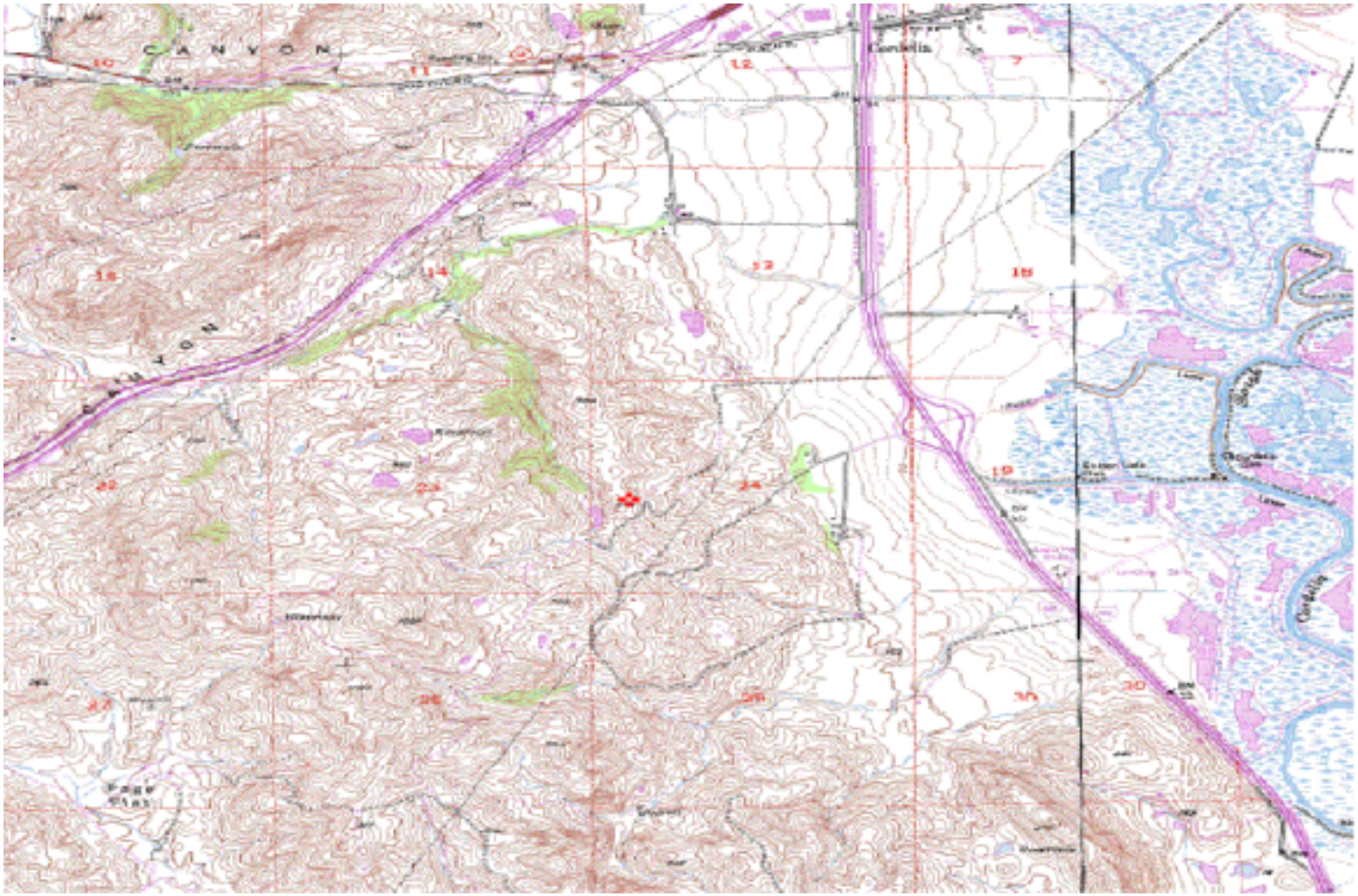
Figure 4. SAM results for both AVIRIS and HyMap data. Differing spatial resolutions, bandwidths, and SNRs effect mapping results. HyMap data clearly has more detail. However, microorganisms in magenta and red map in all three datasets, as well as zonation patterns (albeit crudely in AVIRIS 1992 data).

HyVista, UCSC, LLNL teams and the plane with HyMap hyperspectral sensor on board

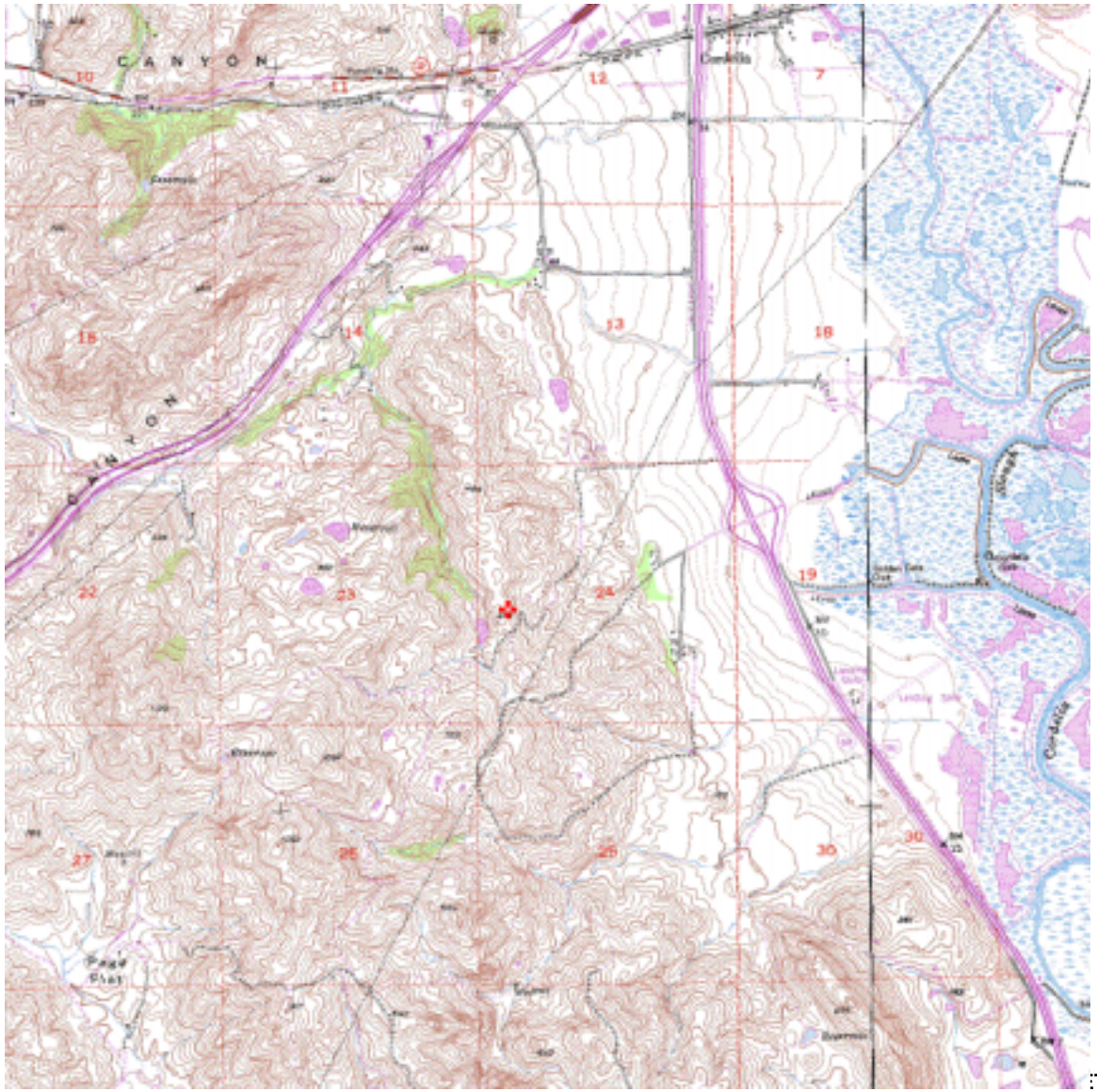
Airborne Hyperspectral image costs

- We currently contract airborne hyperspectral imagery acquisition from HyVista Corp. http://www.hyvista.com/
- 288 Km of 1.2 Km wide flight lines of Hyperspectral visible and near infrared images, with 3 meter spatial resolution, costs about 60k$ and takes about 1 day.
- Proprietary imagery costs considerably more
- The data is georectified on-line by the onboard differential GPS. The lay days are 15 K$ each and there is normally a one time 50 K$ fee for mobilization of the sensor from Australia to the US.
- Cost can be reduced considerably by sharing images between programs

Cordelia California PG&E Pipeline site



Cordelia California PG&E Pipeline site



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